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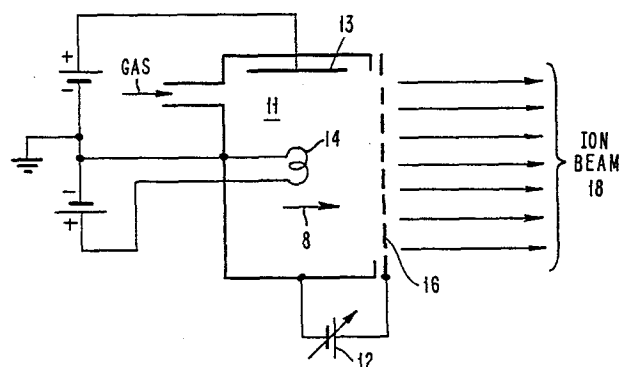
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Method of producing a neutralised low energy ion beam, neutralised low energy ion beam generator and method of producing a neutrillised high energy ion beam.

A neutralised low energy ion beam is produced by forming a plasma between an anode (13) and a cathode (14) and maintaining a grid (16) at a potential slightly more positive than the cathode (14) so that a beam containing positive ions and high energy primary electrons from the plasma passes through the grid (16).

A neutralised high energy ion beam is produced by directing (Fig. 4) a low energy beam containing charged particles of opposite polarity to that of the ions in an unneutralised high energy ion beam across the latter beam. The low energy beam may be one produced by a generator (Fig. 1) as described above or another ion source and an electron source (21).



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METHOD OF PRODUCING A NEUTRALISED LOW ENERGY ION BEAM,
NEUTRALISED LOW ENERGY ION BEAM GENERATOR AND
METHOD OF PRODUCING A NEUTRALISED HIGH ENERGY ION BEAM

The present invention relates to the generation of neutralised ion beams and more particularly to method of producing a neutralised low energy ion beam, neutralised low energy ion beam generator and method of producing a neutralised high energy ion beam.

Sputtering techniques for precisely machining the surface of a target substrate are well known. These techniques require the generation of an ion beam at a sufficient energy level to remove atomic particles from a target surface of the substrate by bombardment with the ion beam. The sputtered particles may themselves be deposited through suitable masking onto a second substrate to form a precise deposition layer for an electronic component.

The efficiency of sputtering systems of the prior art is limited when bombarding substrates which are insulators because of an electric charge which develops on the surface of the target area. The charge can be reduced by adding to the incident ion beam free electrons, in the case of a positive ion sputtering beam, or positive ions in the case of a negative ion sputtering beam.

In the case of a positive ion beam, free electrons have been added to the positive ion beam by means of a separate emitter, in the path of the ion beam, usually a filament carrying an electrical current. This technique of neutralising the beam adds free electrons to the ion beam neutralising the charge at the substrate surface.

Several disadvantages are encountered when using the filament neutralising technique, the first of which is contamination of the substrate. It is not unusual for the filament to evaporate or sublime whereby contaminants are added to the ion beam.

Placing the filament in the ion beam also causes the substrate to be heated which in the case of some substrates causes degradation of the substrate surface. Additionally, the filament is subject to bombardment by the incident ion beam thereby sputtering filament particles into the ion beam which end up on the substrate.

One prior art technique of producing a neutralised ion beam is described in U S Patents 3,523,210 and 3,515,932. This neutraliser requires that a certain beam current level be established to maintain a bridge of plasma for adding neutralising electrons to the ion stream. Thus, neutralisation is dependent on a current intensity sufficient to form a plasma bridge wherein a portion of the plasma exits the plasma generator to enter the ion stream. Low current ion beam production cannot therefore make use of this technique because of the current requirements necessary with plasma bridge neutralisation. The plasma bridge neutralisation technique generates a plume of ions and electrons resulting in a poorly directed beam incapable of being aimed at a distant target.

The present invention seeks to provide solutions to the problem of generating neutralised ion beams which do not suffer from the disadvantages of being contaminated and/or causing excessive heating of a substrate target.

According to one aspect of the invention, a method of producing a neutralised low energy ion beam comprising passing an electrical current between an anode and a cathode in a gas filled chamber to produce a plasma containing positive ions, high energy primary electrons and low energy background electrons, is characterised by establishing such a potential on a grid disposed to one side of the plasma that positive ions and high energy primary electrons from the plasma flow through the grid thereby producing a neutralised low energy ion beam.

According to another aspect of the invention, a neutralised low energy ion beam generator comprises a chamber containing an anode and a cathode, means to introduce an ionisable gas into the chamber, and means

to provide a potential difference between the cathode and the anode to form a plasma; the generator being characterised by one wall of the chamber being in the form of a grid disposed to one side of a direct path between the anode and the cathode and means to maintain the grid at a potential slightly more positive than the cathode whereby ions and high energy primary electrons from the plasma flow through the grid to thereby produce a neutralised low energy ion beam.

According to a further aspect of the invention, a method of producing a neutralised high energy ion beam is characterised by directing across an unneutralised high energy ion beam, a relatively low energy beam containing charged particles of opposite polarity to that of the ions in the unneutralised ion beam.

How the invention can be carried out will now be described by way of example, with reference to the accompanying drawings, in which:-

Figure 1 represents a generator embodying the invention, for providing a self-neutralised low energy ion beam;

Figure 2 indicates the potential distribution in the generator of Figure 1,

Figure 3 indicates the energy distribution of electrons in the chamber in the generator of Figure 1, and

Figure 4 represents a system for producing a neutralised high energy ion beam.

A neutralised low energy ion beam generator (Figure 1) comprises a chamber 11 for receiving a gas to be ionised. The gas may be, for example, argon with a chamber pressure of 1m Torr (0.133N/m^2) 1m Torr. A magnetic field 8 is established across the chamber 11 to increase its ion producing efficiency.

A filament 14 is connected to a source of electric potential and thereby emits electrons. An anode 13 is maintained at a potential for attracting the electrons.

The migrating electrons have an energy level distribution as shown in Figure 3. The first major electron population has a low energy Maxwellian distribution. The second major electron population comprises a group of high energy primary electrons. The electrons which migrate within the chamber 11 collide with gas atoms producing both positive ions and low energy electrons. A plasma forms having a potential several volts positive of the anode.

A grid 16 having a plurality of apertures is maintained at a potential for accelerating the positive ions in the plasma through the apertures to the exterior of the chamber 11. A sheath forms between the plasma and grid as a boundary for the plasma due to the potential on the grid 16.

The generator of Figure 1 is capable of supplying to the positive ion beam negative electrons for neutralising the beam. To make use of the electrons within the plasma as neutralising particles, the grid 16 is maintained at a potential slightly positive of the cathode 14 within the chamber 11. The potential distribution within the chamber 11 for this condition is shown in Figure 2. The cathode 14 potential is established to be zero volts. The anode is held at a voltage of 40 volts positive of the cathode. The plasma assumes a positive potential with respect to the cathode, and a voltage gradient exists between the plasma, cathode 14 and grid 16 forming a sheath for the plasma.

The single grid 16 is maintained at a slightly positive voltage, typically 1-5 volts, with respect to the cathode 14. The advantage of maintaining a potential distribution within the chamber 11 as shown in Figure 2 is the introduction of free electrons into the positive ion beam 18 formed at screen grid 16. The positive voltage on the single grid 16 permits high energy primary electrons (Figure 3) to migrate

towards the grid. These primary electrons balance the charge provided by the ions exiting the grid 16.

The high energy primary electrons in the plasma which exit through grid 16 have dissipated much of their kinetic energy in passing over the grid 16 and have an energy level desirable for neutralisation.

The grid 16 potential is maintained at a desirable level for promoting a positive ion, self neutralised beam by either allowing the grid to float and assume a potential established by the collision of electrons and ions on the grid, or by using a power supply 12 connected between the grid 16 and the chamber 11 as shown in Figure 1.

To further reduce the possible contamination of the generated ion stream, the cathode 14 is located at a position within the chamber 11 so that no line of sight path exists between the target irradiated with the ion beam and the cathode 14. This apparatus for generating a self neutralised beam is particularly useful in low energy ion beam formation having an energy of less than 100 ev.

The ion source of Figure 1, being self neutralised, is useful for neutralising other, higher intensity ion beams as will be described with reference to Figure 4. More generally, a sputtering beam is neutralised by a secondary low energy ion beam which intersects the sputtering beam. The secondary beam contains particles having the appropriate charge for neutralising the sputtering beam, positive ions in the case of a negative ion sputtering beam, and free electrons in the case of a positive ion sputtering beam. The low energy beam provides for minimum interaction with the sputtering beam and surrounding vacuum facility.

Referring now to Figure 4, a secondary, low energy beam 22 is directed towards a primary sputtering beam 24. The arrangement of Figure 4 is useful for neutralising both positive ion beams and negative ion beams. The primary sputtering beam is generated by a multi-grid, high energy ion accelerator 25.

The arrangement of Figure 4 does not require the particular ion source of Figure 1 to generate the secondary beam. The use of a refractory metal filament 21 external to the ion source 20 will provide free electrons which will neutralise both the secondary and primary ion beams 22, 24 generated by ion sources 20 and 25. The filament 21 can be located at least 10 cm from the main beam so that heating of the substrate can be minimized. In either type of secondary low energy beam generation, self-neutralised or externally neutralised, the single grid 28 ion source is contemplated for providing an adequate secondary ion beam. The single grid accelerator is used also in those applications where a positive ion beam neutralises a negative ion beam. In a negative ion beam, positive ions from a secondary beam eventually appear as randomised thermal energy.

The neutralisation capability of this secondary ion beam is demonstrated considering the following example. Assuming that a secondary, 30 ev argon beam of positive ions is used to carry electrons for neutralising both beams, having a radius of 1 cm and a current density of 1ma/cm², the ion velocity can be determined as:

$$\begin{aligned} V_1 &= 1.389 \times 10^4 [E(\text{ev})/M_1(\text{amu})]^{1/2} \\ &= 1.389 \times 10^4 [30/40]^{1/2} \\ &= 1.20 \times 10^4 \text{ m/s} \end{aligned}$$

The ion and electron density is

$$\begin{aligned} n &= J^i / q V_1 = 10 / 1.602 \times 10^{-19} \times 1.20 \times 10^4 \\ &= 5.2 \times 10^{15} \text{ m}^{-3}, \end{aligned}$$

where J^i is the current density, and q is the charge of an electron. The saturation electron current through the beam is calculated as follows.

$$J^s = nqvA/4,$$

where A = beam cross sectional area, and

v = beam electron velocity.

For an average neutraliser, the electron temperature would be expected to be 1-2ev, producing mean electron velocities of 6.69×10^5 m/s to 9.46×10^5 m/s. This produces a saturation current J^s of between 44ma and 62ma when applied as above.

Thus, the 30 ev argon beam is capable of producing a saturation electron current within 44-62ma. The electron current can in accordance with the above calculation be increased with a higher electron temperature or by increasing the cross section area of the beam.

The potential drop across the secondary beam over a 10cm length should not significantly affect the electron current capacity of the second beam. Considering a typical plasma resistivity for electron energies of 1-2ev, the resistance of a 10cm length of the secondary beam should be between .20 ohms and .08 ohms thereby providing a voltage drop of 9mv and 5mv respectively. This should only minimally affect the electron current carrying capability of the beam.

CLAIMS

1. A method of producing a neutralised low energy ion beam comprising passing an electrical current between an anode and a cathode in a gas filled chamber to produce a plasma containing positive ions, high energy primary electrons and low energy background electrons, the method being characterised by establishing such a potential on a grid disposed to one side of the plasma that positive ions and high energy primary electrons from the plasma flow through the grid thereby producing a neutralised low energy ion beam.
2. A method as claimed in claim 1, in which the grid is maintained at a potential of from 1 to 5 volts positive with respect to the cathode.
3. A neutralised low energy ion beam generator comprising a chamber (11) containing an anode (13) and a cathode (14), means to introduce an ionisable gas into the chamber, and means to provide a potential difference between the cathode and the anode to form a plasma; the generator being characterised by one wall of the chamber being in the form of a grid (16) disposed to one side of a direct path between the anode (13) and the cathode (14) and means to maintain the grid at a potential slightly more positive than the cathode whereby ions and high energy primary electrons from the plasma flow through the grid to thereby produce a neutralised low energy ion beam.
4. A neutralised low energy ion beam generator as claimed in claim 3, in which the cathode is disposed at such a position in the chamber to minimize contamination of the neutralised low energy ion beam.
5. A method of producing a neutralised high energy ion beam characterised by directing across an unneutralised high energy ion beam, a relatively low energy beam containing charged particles of opposite polarity to that of the ions in the unneutralised ion beam.

6. A method as claimed in claim 5, in which the ions in the unneutralised high energy beam are of negative polarity and the low energy beam contains positive ions.
7. A method as claimed in claim 5, in which the ions in the unneutralised high energy beam are of positive polarity and the low energy beam contains free electrons.
8. A method as claimed in any of claims 5 to 7, in which the low energy beam is generated from a plasma.
9. A method as claimed in claim 8, in which the low energy beam is produced by a method as claimed in claim 1 or claim 2 or by a generator as claimed in claim 3 or claim 4.

FIG. 1

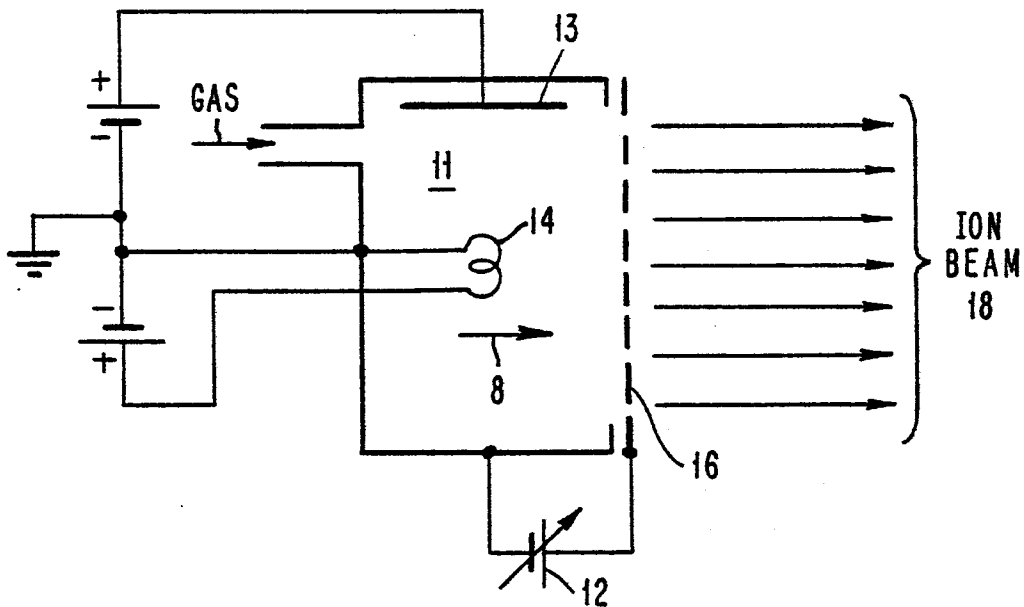


FIG. 2

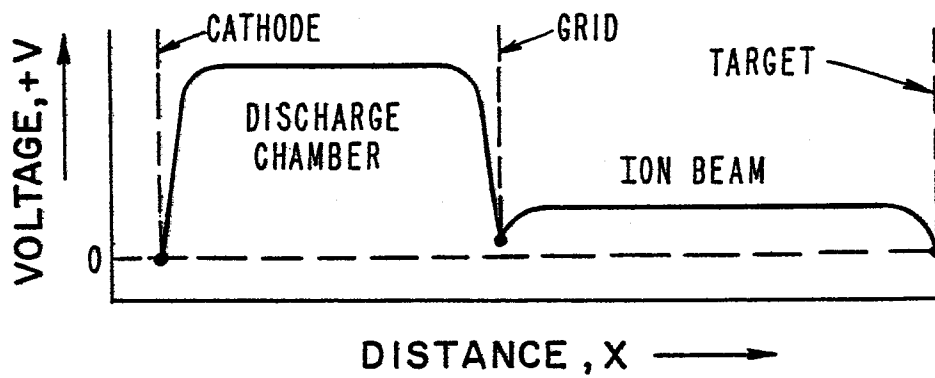


FIG. 3

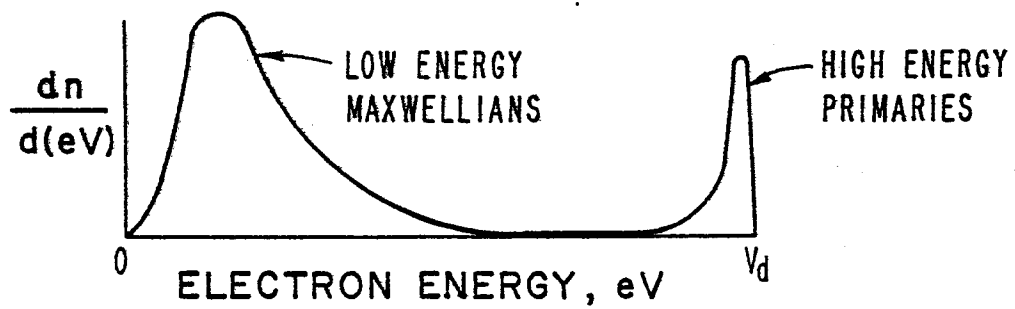


FIG. 4

